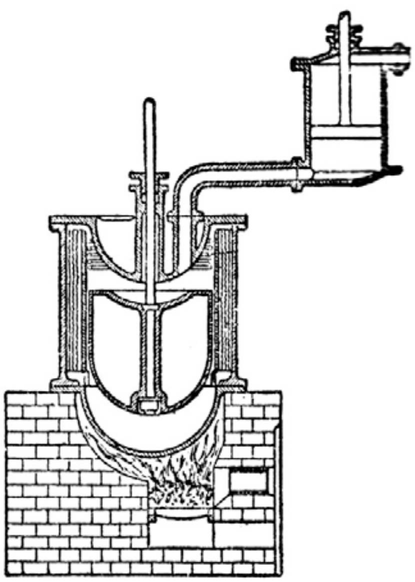
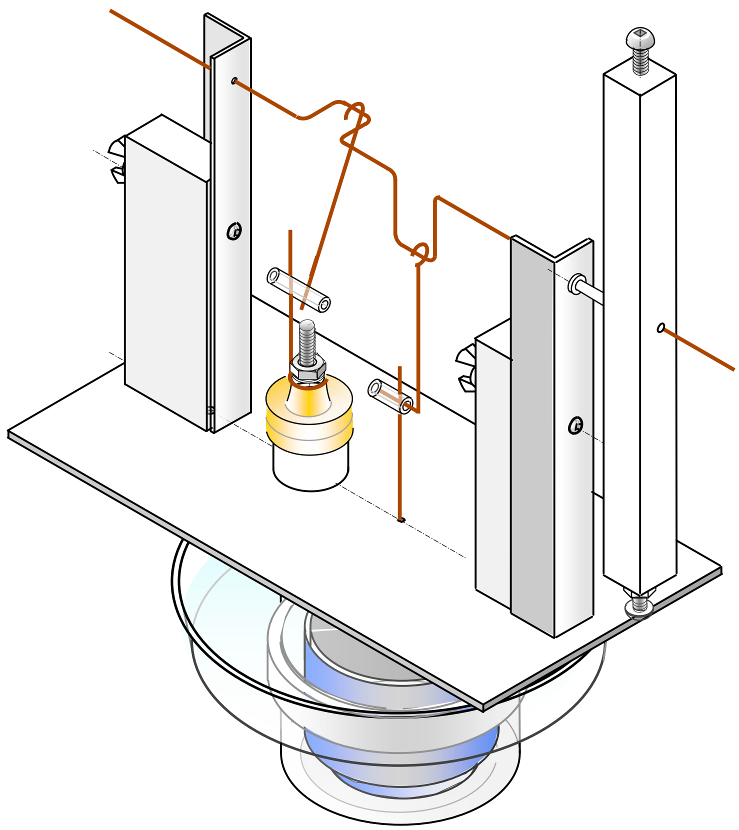
centre de développement pédagogique
pour la formation générale en science et technologie

Working document

THE STIRLING ENGINE





STUDENT BOOKLET

January 2009

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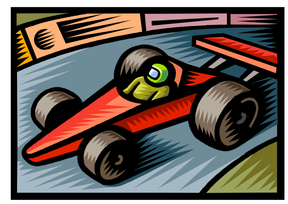
Once upon a time a surprising machine!

NOTE **This activity was designed within the framework of teacher training sessions. It will require adaptation before being used with students.**

Gases are present all around us. In certain cases, they maintain life, as is the case with oxygen, whereas in other cases, they are fatal, like chlorine gas. Technological applications using gases are numerous. We only have to think of barbeques or air bags and internal combustion engines in our cars to be convinced of this fact. We invite you now to discover one of the most incredible machines using a gas. The type of engine we are about to present to you will most certainly enthrall you!



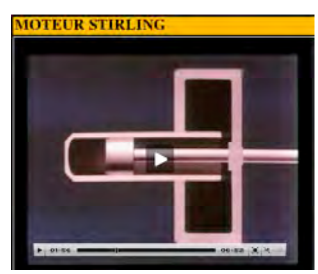
Indeed, the hot air engine is a very surprising machine. In this type of engine, there are no explosions like in the ones currently used in our cars. It is thus entirely safe for laboratory study.

It was not invented lately. In fact, the patent for the hot air engine (the Stirling engine) was deposited on September 27th, 1816. For competitive reasons, the engine designed by Scotsman Robert Stirling never knew commercial success. It was supplanted in turn by the steam boiler and the internal combustion engine.

With an output clearly superior to that of internal combustion engines, however, the Stirling engine surely has a bright future. Indeed, current ecological concerns over energy conservation and biofuels make this engine very interesting, since it can function on any kind of fuel (straw, wood, alcohol, the sun's rays…)

Your challenge

We are proposing to have you discover, through experimentation, the scientific and technological principles used in the construction of the Stirling engine. To do so, you will need to become familiar with the concepts relating to the physical properties of gases. Then, you will have the opportunity to operate a real Stirling engine in order to scientifically analyse this wonderful technological application.



To start, we invite you now to discover this exceptional engine by listening to this short (barely 7 minute) report (French).
http://leweb2zero.tv/video/alfred_42461927d59459f
The beginning of this next video presents an actual application of the Stirling engine, regarding the production of solar energy.

- http://www.eco-energie.ch/content/view/112/47/

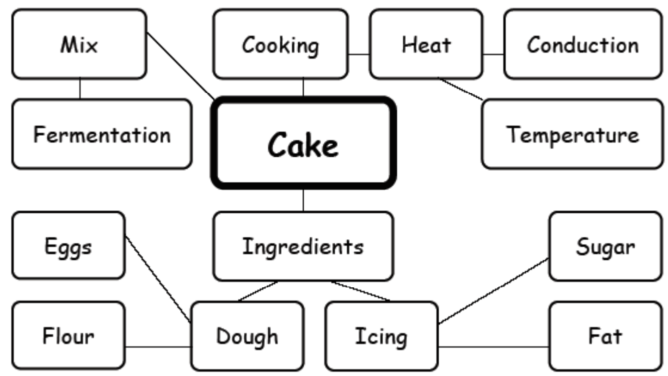
Let's warm up a little

Here now is a short video showing you the Stirling engine that you will have to operate later on in the project. This engine was specially designed for you. Its slow rotation speed and transparent side allow you to see its components in action. Observe the way in which it moves and take notes!
http://www2.cslaval.qc.ca/star/Le-moteur-Stirling

Based on your current knowledge and on what you understood from the video presentations you have seen, write a summary explanation of the function of the Stirling engine.	**Give yourself a representation of the engine (sketch)**

Now build a network of concepts related to the study of the function of the Stirling engine. Building this network will allow you to organize your knowledge in the form of a visual card. This card will give you a good idea of the strategies that will allow you to better understand how the Stirling engine works.

Example of a network of concepts



Network of concepts

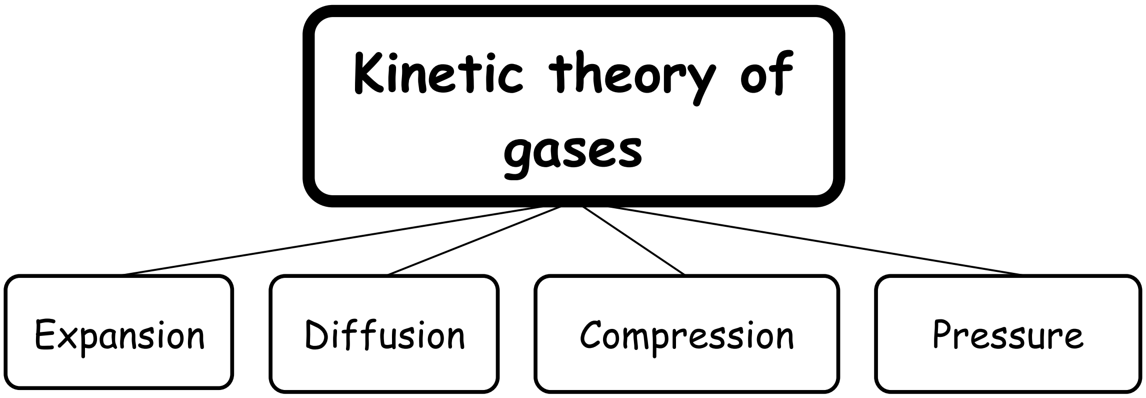
Stirling Engine

Kinetic theory of gases

Question: How do gases behave?

Observe the demonstrations and complete the following texts in such a way as to remember the essential facts.

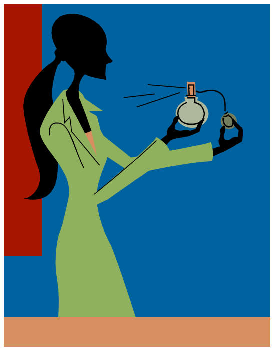
Explorations card



Expansion of a gas (molecular movement of gases)

The molecules of a gas are like little ________ that move in all directions. Normally, these particles move in a _______ line unless they hit other gas, liquid or solid particles. In this way, gases always _______ their container, taking all the available space. The soccer ball shown here to the left is a good example of this. Finally, a gas has neither a precise _________ nor volume, contrary to solids, for example.

Diffusion of a gas



Gas molecules move in _____ directions. A certain gas can, in this manner, spread throughout another gas. The _________ of a gas in a room may take a certain time. How many seconds does it take for the ________ to get to your nostrils? What do you do if the __________ becomes unsupportable?

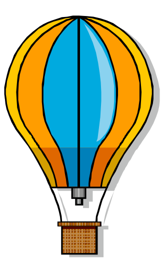
Compression of a gas

Contrary to _______, gases are compressible. It is possible to make the ___________ of a gas vary considerably by modifying the pressure exerted upon it. This increase in _________ brings the molecules closer to one another. That is why you can inject a large volume of air into a _________ bicycle air chamber, for instance.

Pressure of a gas

The ______________ pressure that we are currently subjected to is the result of innumerable collisions that occur between air molecules and our body. Each air molecule that _______ us has a mass and a speed and produces a small thrust on our skin. It is the sum of all these small _________ that generates atmospheric pressure. In the case of air compressed into a diver's tank, these collisions are _________ numerous since the molecules are condensed into a smaller volume. The pressure is a measure of force per unit of surface (Newtons per square meter, for instance).

Heating a gas



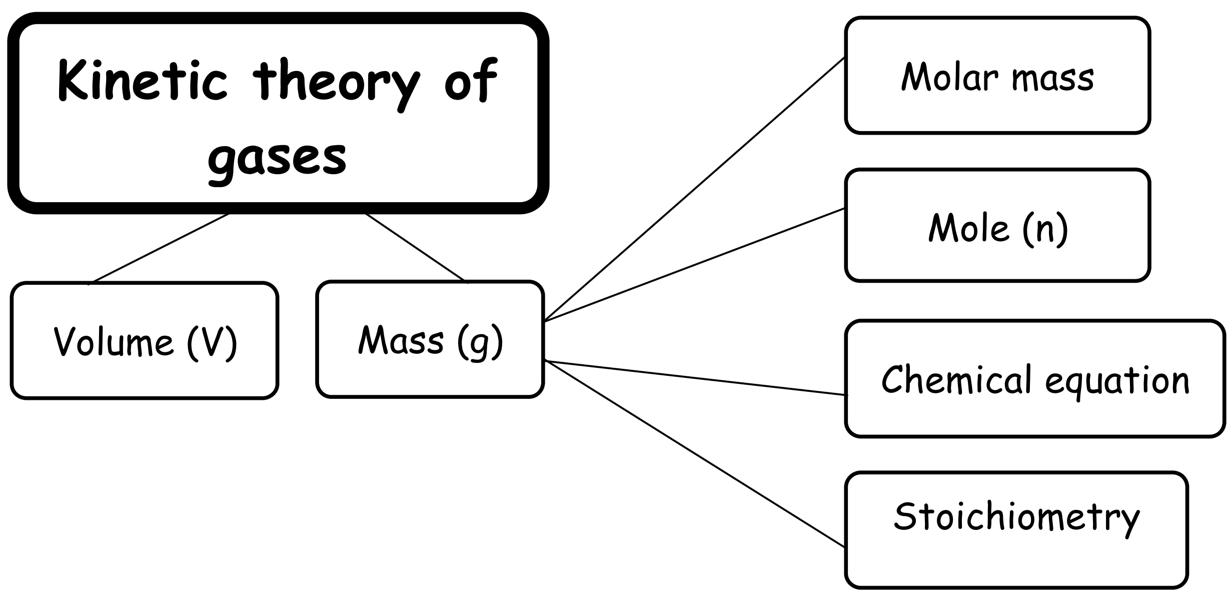
The hot air balloon to the left here reminds us that heating a gas causes an ___________ in its volume. In addition, everyone knows that it's not a good idea to throw an aerosol container into a fire. The increase in temperature would cause an ____________ in the pressure of the gas

Number of molecules and volume of a gas

Questions: How does the number of gas molecules (the number of moles) vary when we make the volume of a gas vary? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes? What should remain constant throughout the experiment? How can this study bring you to a better understanding of the Stirling engine?

Prove experimentally and show mathematically.

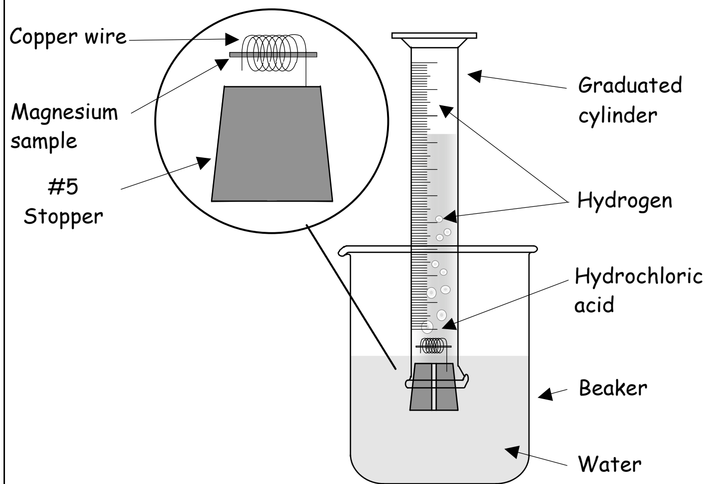
Explorations card



Material

- Protective glasses
- 125 mL hydrochloric acid
- 1 - 100 mL graduated cylinder
- 1 eye-dropper
- 20 cm of magnesium ribbon
- 1 scale
- 1 ruler
- 1 pair of scissors
- 1 - #5 stopper adapted to the 100ml cylinder and having a copper wire spring
- 400 mL tap water
- Food coloring
- 1 agitator
- 1 container or tray to manipulate spillage
- 1 - 400 mL beaker
- 1 – 600 mL beaker

Sketch of the assembly



Useful chemical equation

$\mathbf{Mg_{(s)} + HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}}$ (Is it balanced?)

Manipulations

1. Cut 20 cm of the magnesium ribbon.
2. Weigh the ribbon and note its value.
3. Cut the ribbon to form pieces of 2,3,4,5 and 6 cm long.
4. Calculate the masses of the small pieces by using a proportion and note these masses.
5. Pour 500 mL of coloured water in a 600 mL beaker (the presence of the food colouring allows us to distinguish between the acid and the water when they are mixed.)
6. Pour 250 mL of tap water in a 400 mL beaker. It will be used to recuperate the acid.
7. Place the first (2 cm) sample of magnesium in the middle of the copper wire spring attached to the stopper and fold back its extremities.
8. Measure 25 mL of 6 mol/L hydrochloric acid using the graduated cylinder.
9. Gently add the coloured water to the acid to <u>completely</u> fill the cylinder (this should form two layers because the density of the acid is greater than that of the water).
10. Place the stopper on the cylinder and push it down enough to make the coloured water overflow. (Be careful not to push it down so much that the neck of the cylinder breaks. In any case it is not necessary for the cylinder to be watertight).
11. Rapidly turn the cylinder upside down into the 400 mL beaker destined for acid recovery.
12. Watch the acid come into contact with the magnesium and wait for its complete disappearance.
13. Note the volume of gas accumulated in the cylinder.
14. Recuperate the water and acid in an appropriate container.
15. Rinse the copper spring and the graduated cylinder.
16. Perform manipulations 6 to 15 again with the other four samples.

Directed laboratory

In one sentence, summarise your objective:

In one sentence, formulate your hypothesis:

Which factors are the constants in this experiment (number of moles, temperature, pressure, volume)?

Recap your protocol in the form of a diagram.

Data table		
	Mass of magnesium (gram)	**Volume of hydrogen (millilitre)**
2 cm. piece of magnesium		
3 cm. piece of magnesium		
4 cm. piece of magnesium		
5 cm. piece of magnesium		
6 cm. piece of magnesium		
20 cm. piece of magnesium		

Analyse the results

Process your data.

Question 1

Balance the following equation: $Mg_{(s)} + HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$

Question 2

Considering the preceding balanced equation, how many hydrogen moles are produced by the quantities of magnesium present in the data table below?

	Quantity of hydrogen (mole)
2 cm. piece of magnesium	
3 cm. piece of magnesium	
4 cm. piece of magnesium	
5 cm. piece of magnesium	
6 cm. piece of magnesium	

Process your data (continued)

Emphasise the tendencies

Question 3
By drawing the graph of volume versus number of hydrogen moles, what mathematical relationship do you see?

____

____

____

Question 4
Calculate the rate of variation in this relationship.

____

____

Draw your conclusions
Question 5
Keeping in mind this rate of variation, relate two points of the curve. In other words, for any two given points on the graph, complete the following ratio:

$$\frac{V_1}{n_1} = \text{------------}$$

Question 6
In the case of the Stirling engine, why could a greater volume of gas be desirable?

____

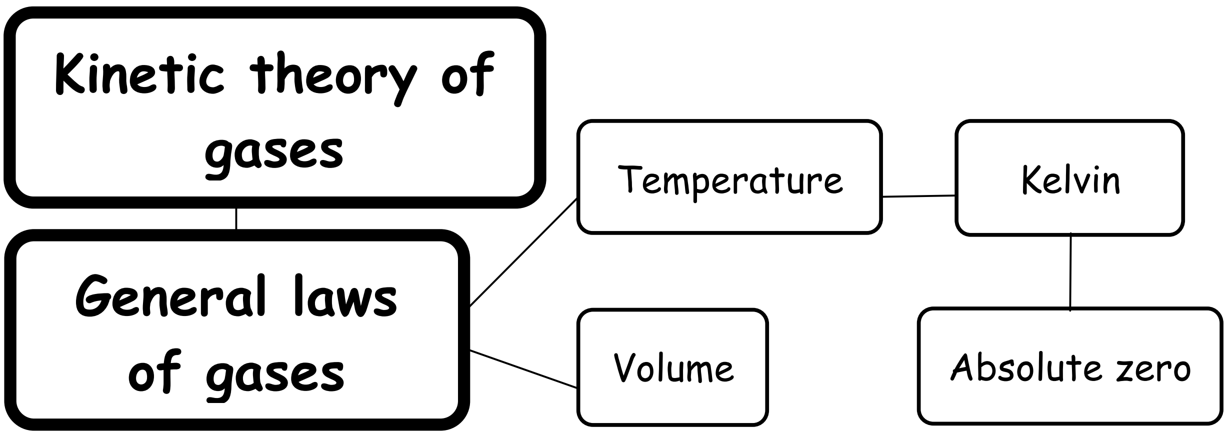
____

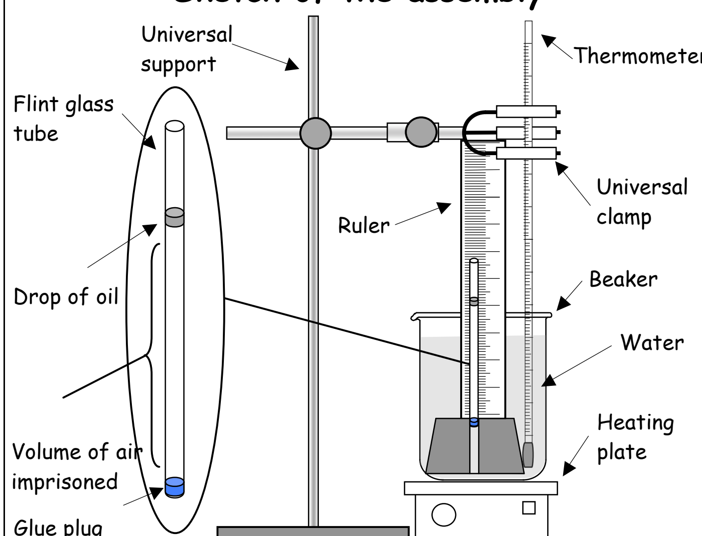
The effect of temperature on the volume of a gas (Charles Law[1])

Questions: What is the effect of a variation in temperature on the volume of a gas? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes? What should remain constant throughout the experiment? How can this study bring you to a better understanding of the Stirling engine?

Prove experimentally and show mathematically.

Explorations card



Material	Sketch of the assembly
• 1 – 5 mm diameter, 10 cm long tube of flint glass • 5 universal supports • 5 thermometer clamps • 5 - 400 mL beakers • 5 thermometers • 3 heating plates • 1 beaker clamp • Ice • Water at room temperature • Tap water • 1 ruler	

[1] French physicist Jacques Alexandre César Charles (1746-1823)

Manipulations

1. Fill the first 400 mL beaker with ice and water and wait until the temperature of the water stabilises.
2. Fill the second 400 mL beaker with water at room temperature.
3. Fill three other 400mL beakers with water and bring their temperatures to the following values using the heating plates: beaker no.3 ≈ 50 °C, beaker no.4 ≈ 75 °C and beaker no.5 ≈ 85 °C.
4. Plunge the glass tube into each of the five beakers in turn, carefully noting the height of the imprisoned air as well as the temperature of the water into which the tube is plunged. (Take care to wait for the temperature of the air in the tube to reach the same temperature as the water.)
5. Note these heights and corresponding temperatures in your data table.

Reminder of a useful equation (volume of a cylinder)

$V=h \cdot S$ Where V ⇒ volume of cylinder in cm^3, h ⇒ height of the volume of air imprisoned in cm, S ⇒ surface in cm^2
$S=\pi \cdot r^2$ Where S ⇒ surface of a circle in cm^2, π ⇒ constant equal to 3,1415927, r ⇒ radius of a circle in cm

Important information (internal diameter of the glass tube): 0,295 cm
(This value needs to be confirmed with your teacher)

Directed laboratory

In one sentence, summarise your objective:

In one sentence, formulate your hypothesis:

Which factors are the constants in this experiment (number of moles, temperature, pressure, volume)?

Recap your protocol in the form of a diagram.

Data table		
	Temperature of the imprisoned air (°C)	Height of the volume of imprisoned air (cm)
In melting ice		
At room temperature		
At about 50 °C		
At about 75 °C		
At about 85 °C		

Analyse the results

Process your data

Question 1

Convert the temperatures (degrees Celsius ⇒ Kelvin). In addition, considering the equation giving the volume of a cylinder as well as the diameter of the flint tube, what is the volume of air imprisoned for each situation?

___

___

	Temperature of the imprisoned air (K)	Volume of imprisoned air (cm^3)
In melting ice		
At room temperature		
At about 50 °C		
At about 75 °C		
In boiling water		

Analyse the results

Process your data (continued)

Emphasise the tendencies

Question 2
Drawing this graph, what kind of mathematical relationship do you see?

Question 3
Calculate the rate of variation of this relationship.

Draw your conclusions

Question 4

Keeping in mind the graph drawn during the experiment and the mathematical equation that is thus produced, relate two points on the curve. In other words, for any two given points on the graph, complete the following relationship:

$$\frac{V_1}{T_1} = \text{------------}$$

Question 5

On your graph, if you extrapolate your curve towards the lower temperatures, at what temperature does the volume of gas tend to become nil?

Question 6

To what does the temperature found in the preceding question correspond?

Question 7

What temperature in Kelvin (K) corresponds to a temperature of -10 °C?

Question 8

What is the advantage of using the Kelvin scale rather than the Celsius scale in the calculations to come?

Question 9

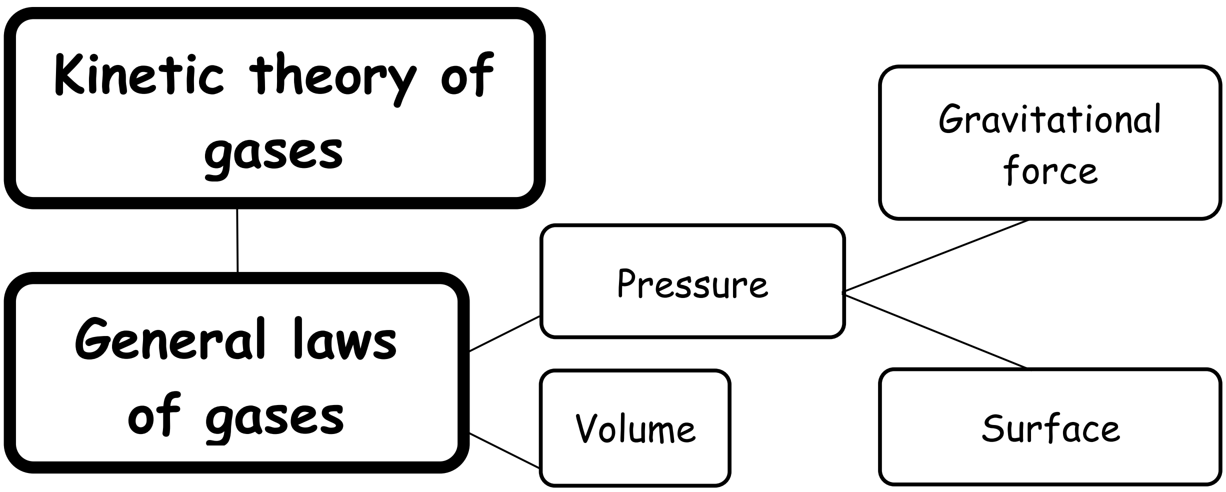
What is the final temperature of 10 L of air at 27 °C if its final volume becomes 1 L? (Be careful, the temperature must be in Kelvin when you calculate!)

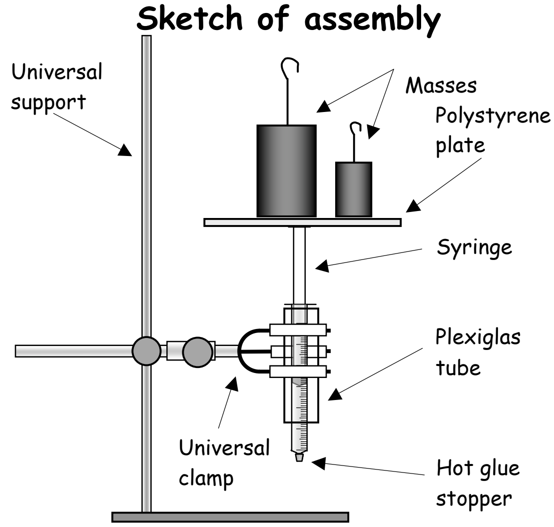
The effect of pressure on the volume of a gas (Boyle-Mariotte's Law[2])

Questions: What is the effect of a variation in pressure on the volume of a gas? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes? What should remain constant throughout the experiment? How can this study bring you to a better understanding of the Stirling engine?

Prove experimentally and show mathematically.

Explorations card



Material	Sketch of assembly
• 1 universal support • 1 universal clamp (nut) • 1 - 1.6 cm diameter, 7 cm long Plexiglas tube • 1 – 1 mL graduated syringe • 1 syringe cap or a little hot glue • 5 masses (100g, 200g, 300g, 400g and 500g)	

[2] Irish chemist Robert Boyle (1627-1691), French physicist Edme Mariotte (1620-1684).

Manipulations

1. Affix the syringe using the clamp and the universal support.
2. Insert the syringe into this assembly. (See assembly sketch above).
3. Place a 100g mass on the plate and note the volume of the syringe in your data table.
4. Perform the preceding manipulations again with the following masses: 200g, 300g, 400g and 500g.

Reminder of useful equations

$F = m \cdot g$ Where F ⇒ force in N (Newton), m ⇒ mass in kg, g ⇒ gravitational acceleration g=9,8 m/s^2

$p = F/S$ Where p ⇒ pressure in N/m^2 or Pa (Pascal), F ⇒ force in N, S ⇒ surface of the syringe in m^2

Important information (diameter of the piston of the syringe) : 4,4 mm
(This value needs to be confirmed with your teacher)

Directed laboratory

In one sentence, summarise your objective:

In one sentence, formulate your hypothesis:

Which factors are the constants in this experiment (number of moles, temperature, pressure, volume)?

Recap your protocol in the form of a diagram.

Data table		
	Mass (g)	**Volume of air (mL)**
1	100	
2	200	
3	300	
4	400	
5	500	

Analyse the results

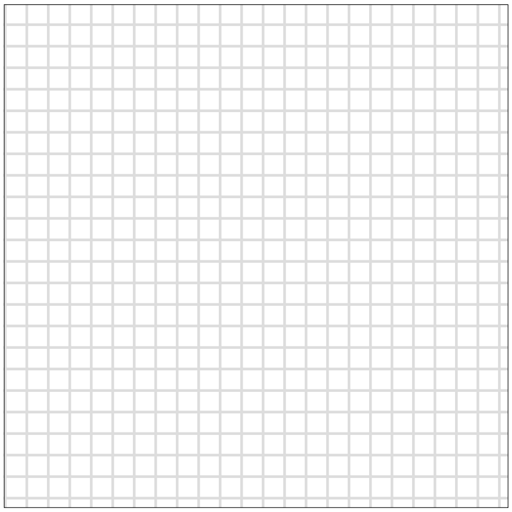
Process your data

Question 1
Using the equation F=m•g, calculate the forces created by the different masses and complete the table below.

Question 2
Using the equation p=F/S and the diameter of the piston of the syringe, calculate the pressures inside the syringe and complete the table below.

Mass (g)	Force (N)	Pressure (kPa)
100		
200		
300		
400		
500		

Process your data (continued)



Emphasise the tendencies

Question 3
Drawing this graph, what kind of mathematical relationship do you see?

Question 4
On your graph, if you extrapolate towards a very small volume, towards where will the pressure tend?

Draw your conclusions

Question 5

Keeping in mind the graph drawn during the experiment, relate two points on the curve. In other words, for any two given points on the graph, complete the following relationship:

$$p_1 \cdot V_1 =$$

Question 6

When the volume quadruples, what will happen to the pressure?

Question 7

The most commonly used units of pressure in chemistry are kilopascals (kPa), millimeters of mercury (mm of Hg) and atmospheres (atm). Knowing that normal atmospheric pressure is: 101.325 kPa = 760 mm of Hg = 1 atm, calculate to what pressure in kilopascal 800 mm of Hg corresponds.

Question 8

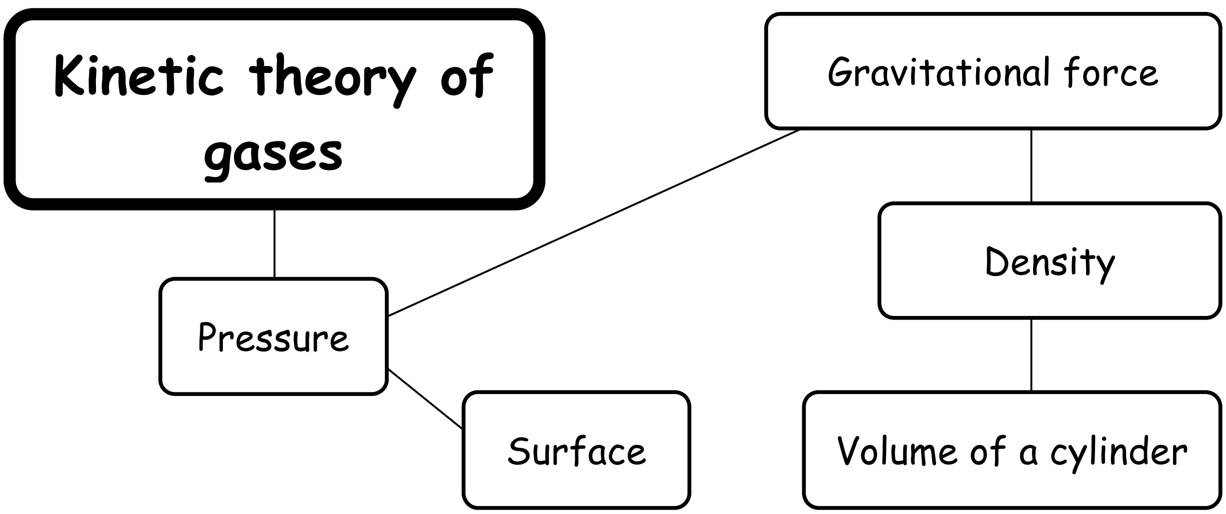
A volume of 40 mL of hydrogen has a pressure of 101.3 kPa. What will its volume be if the pressure increases to 198.5 kPa?

Function of a liquid column pressure gauge (optional)

Question: What variations in pressure (in kPa) can a 60 centimeter U shaped tube liquid column pressure gauge measure?

Work out with the help of a demonstration and show mathematically.

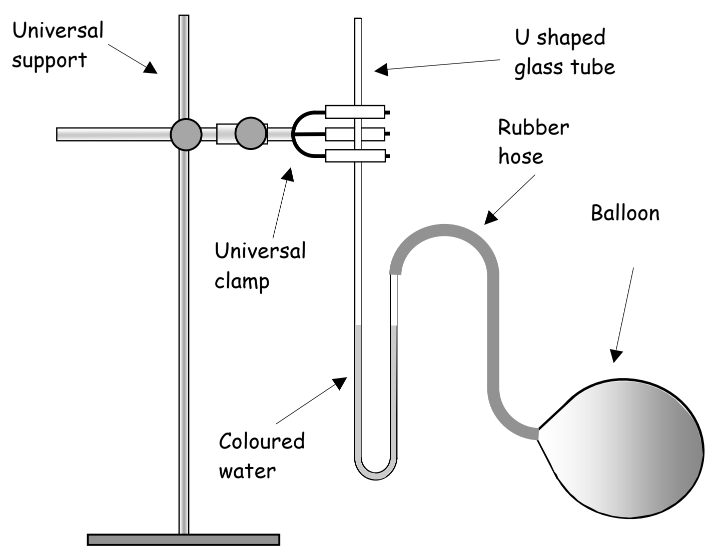
Explorations card



Material

- 1 universal support
- 1 universal clamp (nut)
- 1 - 60 cm glass U shaped tube
- 1 eye-dropper
- Coloured water
- 1 non permanent marker
- 1 rubber hose (that fits onto the glass tube)
- 1 - 10 cm «ty-rap» cable tie
- 1 balloon

Sketch of assembly



Manipulations

1. Affix the glass U shaped tube using the clamp and universal support as shown in the above sketch.
2. Fill the U shaped tube with coloured water using the eye-dropper in order to form a coloured U approximately 15 cm high.
3. Affix a rubber hose to one of the extremities of the glass tube (on the sketch, it is attached to the shorter side of the U shaped tube).
4. Using the marker, indicate the level of water on the free side of the U shaped tube (on the sketch, the longer side of the U shaped tube).
5. Install a balloon onto the other extremity of the rubber tube using the "ty-rap".
6. Press on the balloon with your hand and observe the water displacement.

Directed laboratory

In one sentence, summarise your objective:

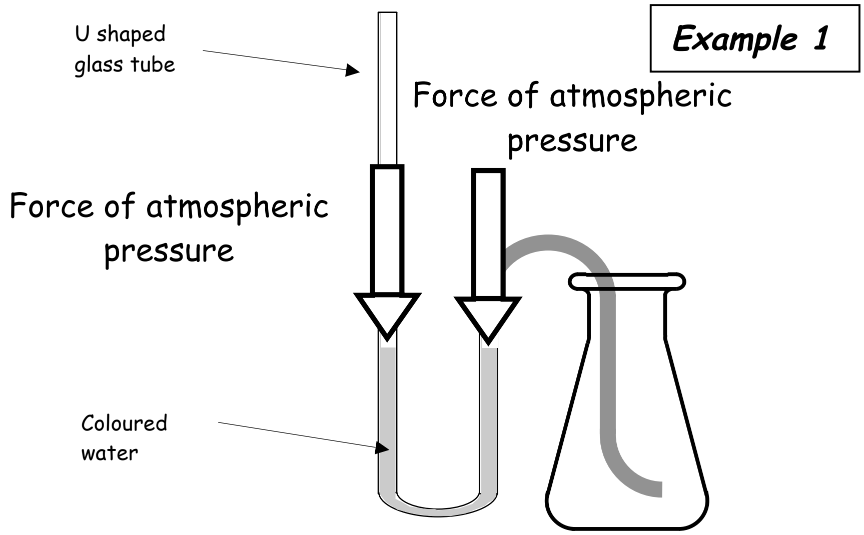
Do you think that this type of pressure gauge can measure a very high pressure? Name one action that, in your opinion, generates too much pressure for this gauge.

Recap your protocol in the form of a diagram.

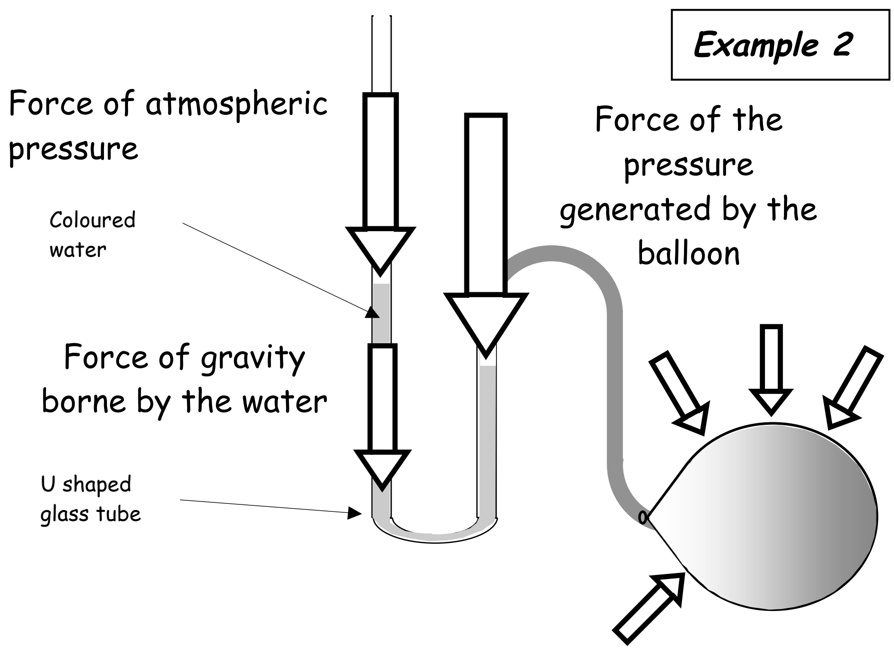
Describe your observations.

Basic principles

In the case represented on the right, the liquid column pressure gauge is in equilibrium between two forces. On each side, it is the force of atmospheric pressure that pushes. That is why the water levels on each side are even.



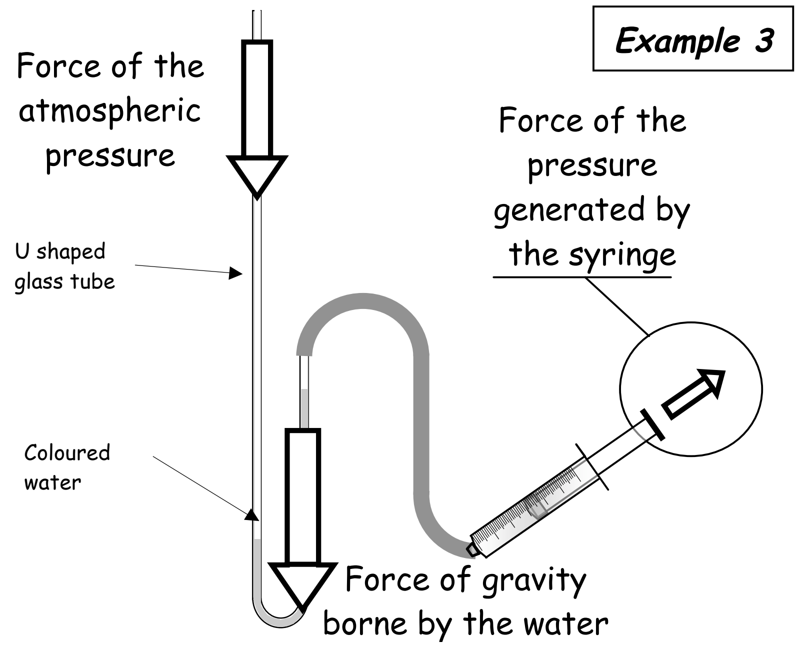
Here, by compressing the balloon, we generate a greater force on the right. That is why the column of water is displaced towards the left. The higher the water rises on the left, the more the force of gravity will seek to bring these particles back down to reach equilibrium. The water will stop rising when the sum of the two left hand forces balances exactly with the right hand force.



Analyse the results

Basic principles (continued)

Here, by pulling on the plunger of the syringe, we create a depression that generates a force in the same direction as the force of atmospheric pressure. The column of water will now move to the right. The higher the water rises on the right, the more the force of gravity will seek to bring these particles back to the bottom in order to reach equilibrium. The water will stop moving when the force of gravity exactly balances to the other two forces.



In the three examples described above, the force of atmospheric pressure was always present. It is therefore clear that atmospheric pressure influences the measurement in this type of gauge.

This observation brings with it the realisation that a liquid column pressure gauge like this one is not an **absolute pressure.** It measures a **relative pressure**. The pressure it gives us is always in relation to the atmospheric pressure.

Note that atmospheric pressure changes according to the weight of the air present in the atmosphere. On average it has a value of 101.325 kPa.

Example 1: Real pressure = atmospheric pressure: 101.325 kPa

Example 2: Real pressure = atmospheric pressure + pressure of gauge

Example 3: Real pressure = atmospheric pressure - pressure of gauge

Possible reinvestment : Torricelli (invention of mercury barometer in 1643)

Analyse the results

Reminder of useful equations

$F_g = m \cdot g$ Where $F_g \Rightarrow$ force in N (Newton), $m \Rightarrow$ mass in kg, $g \Rightarrow$ gravitational acceleration $g=9{,}8$ N/kg

$\rho = m/V$ Where $\rho \Rightarrow$ density in kg/m^3, $m \Rightarrow$ mass in kg, $V \Rightarrow$ volume in m^3

$V = h \cdot S$ Where $V \Rightarrow$ volume in m^3, $h \Rightarrow$ height of the water column in m, $S \Rightarrow$ surface of the water in m^2

$p = F_p/S$ Where $p \Rightarrow$ pressure in N/m^2 or Pa (Pascal), $F_p \Rightarrow$ force in N (Newton), $S \Rightarrow$ surface of the water in m^2

Question 1

Now let's try to understand this type of gauge better. The water that rises on the free side of the U shaped tube bears the force of gravity towards the bottom. Write the equation that describes this force and label it equation (1).

$F_g =$

Question 2

Let's try to determine the mass of water that is lifted. Isolate the mass in the equation describing the density. Write the resulting equation below and label it equation (2).

$m =$

Question 3

Replace the mass in equation (1) with its equivalent in equation (2). Write the resulting equation below and label it equation (3).

$F_g =$

Question 4

The column of water bearing the gravitational attraction is cylindrical. Write the equation describing the volume of a cylinder and label it equation (4).

$V =$

Question 5

Replace the volume present in equation (3) with its equivalent in equation (4). Write the resulting equation below and label it equation (5).

$F_g =$

Question 6

Now let's transport ourselves to the other end of the rubber tube. Now let's see what force you applied to the balloon. Isolate the force in the equation describing pressure. Write the resulting equation below and label it equation (6).

$F_p =$

Question 7

Let's now suppose that we apply a force on the balloon that maintains the water at a fixed height in the glass tube. At that moment, the force of gravity (F_g) equals the force created by the pressure of your hand (F_p) since there is no movement. Now equate F_g and F_p: in other words, equate equations (5) and (6). Label this new equation as equation (7).

Question 8

Simplify the previous equality and indicate what this simplification implies. Label the simplified equation as equation (8).

Question 9

Finally, let's find the maximum pressure value that this type of gauge can bear. To do so, you should need the following quantities:

- The density of water (ρ) = 1 g/cm^3
- The gravitational acceleration on the Earth (g) = 9,8 N/kg
- The maximum height of the column of water. This is measured by measuring the vertical distance between the water levels on each side of the U shaped glass.

N.B. To calculate this pressure successfully, you must pay particular attention to the units of measure. Treat your units of measure so as to obtain pressure in (N/m^2), since this corresponds to the unit of measure for Pascal[3] (Pa). Finally, all you will have to do is to convert this pressure to (kPa).

Maximum pressure = kPa

[3] French physicist Blaise Pascal (1623-1662)

Draw your conclusions

Question 1

What could you do to measure a greater variation in pressure with this liquid column gauge?

Question 2

Is it possible to measure a negative variation in pressure (suction) with this pressure gauge? How would you have to modify the gauge?

Question 3

This type of gauge usually functions with mercury (Hg). Because of its toxicity, we have replaced this liquid metal with coloured water. In your opinion, what advantage would mercury have over water?

Question 4

Knowing that the atmospheric pressure in the laboratory is 100 kPa, determine the real pressure inside an Erlenmeyer flask if the gauge to which it is attached indicated a positive pressure of 3 kPa?

Question 5

Starting with equation (8) from the previous section, find a factor that allows you to determine pressure measured in (kPa) by directly incorporating into that equation the height of the column of water in (cm). In other words, by what constant must we multiply the height of the column of water in the gauge to obtain the pressure?

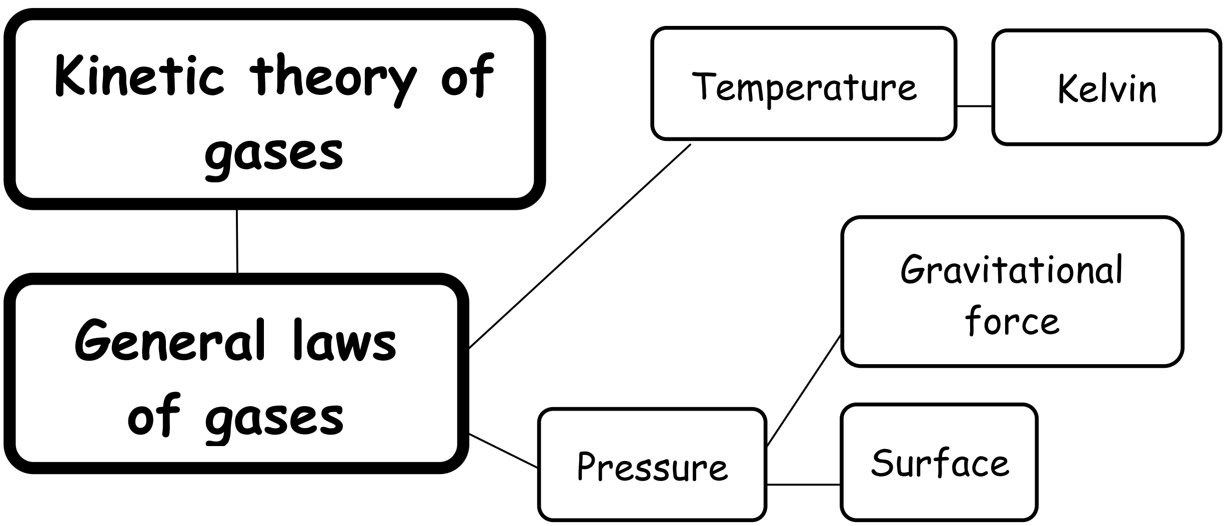
p(kPa) = ______ · height (cm)

The effect of temperature on the pressure of a gas (Gay-Lussac's Law[4])

Questions: What is the effect of a variation in temperature (in K) on the volume of a gas (in kPa)? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes? What should remain constant throughout the experiment? How can this study bring you to a better understanding of the Stirling engine?

Prove experimentally and show mathematically.

Explorations card



Material

- 1 universal support
- 1 universal clamp (nut)
- 1 - 60 cm. U shaped glass tube
- 1 eye-dropper
- Coloured water
- 1 non-permanent marker
- 1 rubber hose (that fits onto the glass tube)
- 1 - #5 rubber stopper with two holes (already prepared as on the assembly sketch)
- A little glycerine
- 1 - 125 mL Erlenmeyer flask
- 1 polystyrene glass
- 1 – 5 mm thick « foamcore » washer 8 cm in diameter
- 1 source supplying 9 volts
- 2 wires with alligator clips
- 1 barometer

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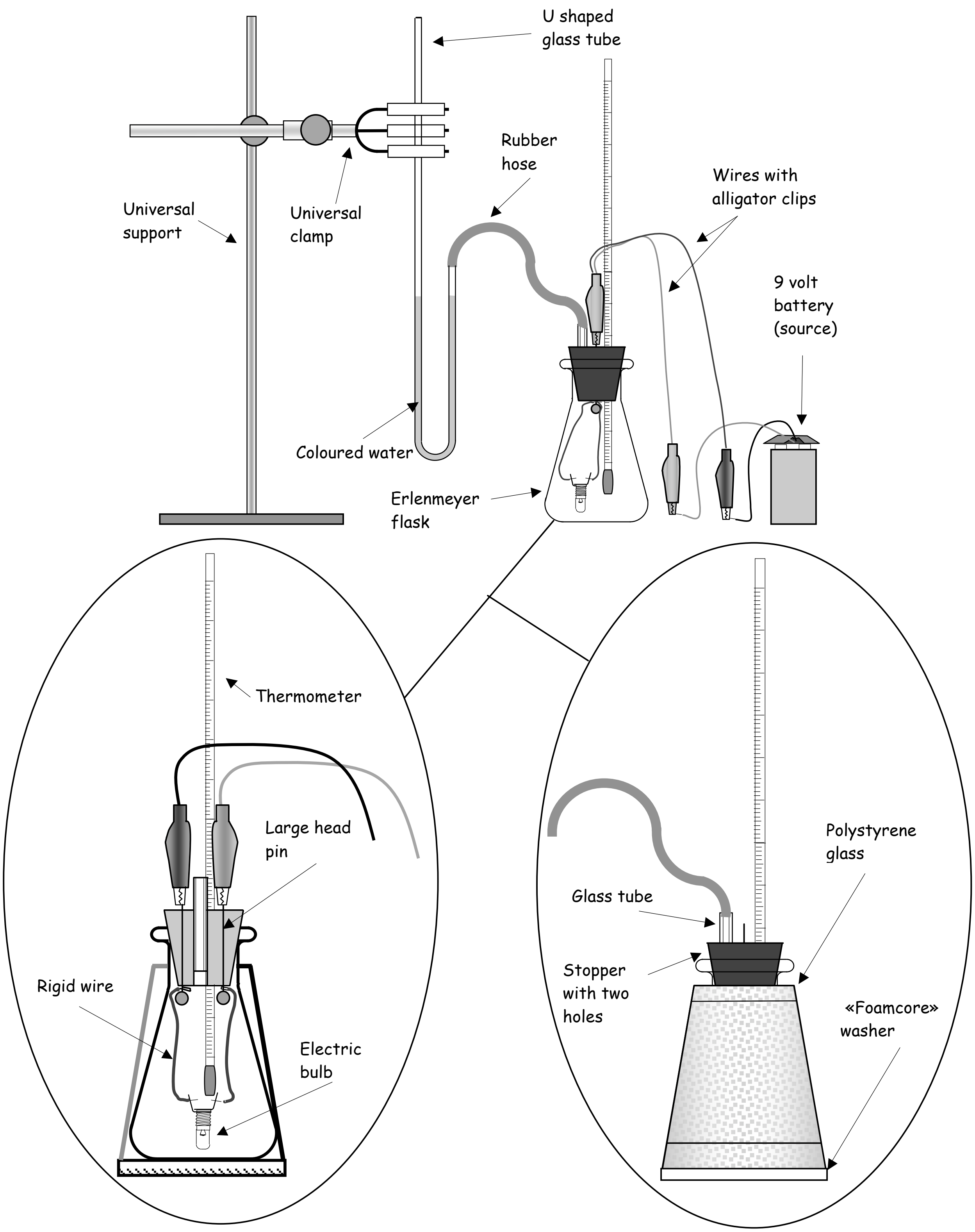
4 French chemist Louis Joseph Gay-Lussac (1778-1850)

Assembly sketch



Note that to correctly perform the calculations needed for your data treatment you must understand how a liquid column gauge works. If this is not the case, carry out the preceding section called « Function of a liquid column pressure gauge”.

Manipulations

1. Affix the U shaped glass tube using the universal clamp and support as in the above sketch.
2. Fill the U shaped glass tube with coloured water using the eye-dropper. You must form a coloured U about 15 cm high.
3. Affix the rubber hose to one of the extremities of the U shaped glass tube (in the sketch, this is the short end of it).
4. Install the rubber stopper on the Erlenmeyer flask.
5. Affix the free end of the rubber hose on the small glass tube already attached to the rubber stopper.
6. Using a non permanent marker, indicate the level of water on the free side of the U shaped glass tube (this level is height zero and corresponds to atmospheric pressure).
7. Note the temperature of the air in the Erlenmeyer flask as well as the surrounding atmospheric pressure.
8. Connect the free extremities of the pins to the source using the alligator clips. **Be careful, the heating has started!**
9. Measure the height of the water for several temperatures below 35°C, for instance at 25°C, 26°C, 27°C…

Directed laboratory

In one sentence, summarise your objective:

In one sentence, summarise your hypothesis:

Which factors are the constants in this experiment (number of moles, temperature, pressure, volume

Recap your protocol in the form of a diagram.

Data table		
No.	**Temperature of the air in the Erlenmeyer flask (°C)**	**Height of the column of coloured water (cm)**
1		
2		
3		
4		
5		
6		
Atmospheric pressure (kPa)		

Analyse the results

Process your data

Question 1

Convert the temperatures (degrees Celsius ⇒ Kelvin). In addition, using the previous section called **«Function of a liquid column pressure gauge»**, calculate the following pressures : (If this section is not completed, your teacher will give you the equation)

No.	Temperature of the air (K)	Relative air pressure (kPa)	Absolute air pressure (kPa)
1			
2			
3			
4			
5			
6			

Process your data (continued)

Emphasise the tendencies

Question 2

Drawing this graph, what kind of mathematical relationship do you see?

____

____

Question 3

Calculate the rate of variation of this relationship.

____

____

Draw your conclusions

Question 4

Keeping in mind the graph drawn during the experiment and the mathematical equation that is thus produced, relate two points on the curve. In other words, for any two given points on the graph, complete the following relationship:

$$\frac{p_1}{T_1} = \text{------------}$$

Question 5

On your graph, if you extrapolate your curve towards the lower temperatures, at what temperature does the pressure of the gas tend to become nil?

____

____

Question 6

To what does the temperature found in the preceding question correspond?

____

____

Draw your conclusions (continued)

Question 7

The normal pressure for the compressed air pressure tank used for the braking system in a truck is at its normal pressure of 931 kPa (135 psi) on a nice winter day. The temperature of the tank is -20 °C. Knowing that the tank risks breakage if the pressure exceeds 1034 kPa (150 psi), what temperature must not be exceeded?

Question 8

In class there are two Magdeburg spheres united by an internal low pressure of 735 mm of Hg. The temperature in class is 22°C and the atmospheric pressure is 760 mm of Hg. By placing the spheres in the sun, their temperature increases to 31°C. Is this increase enough to make spheres will move away from one another?

Question 9

You have air in your mouth that is at 37°C and at 1 atm (atmosphere). At what pressure must you compress this air to elevate its temperature by three degrees Celsius?

Questionnaire on the general laws of gases

Question 1

Complete the synthesis table below:

Physical sizes	Equation
Effect of the variation of temperature on the volume of a gas	$\frac{V_1}{T_1}$ = ------------
Effect of the variation of pressure on the volume of a gas	$p_1 . V_1$ = ------------
Effect of the variation of temperature on the pressure of a gas	$\frac{p_1}{T_1}$ = ------------

Question 2

When you put the three preceding laws together, you obtain the general law of gases. According to this law, the product of the pressure of a gas by its volume is proportional to its temperature in degrees Kelvin. $\{p \bullet V = k \bullet T \rightarrow (p \bullet V)/T = k\}$. It would have been possible to find this equation experimentally while keeping the number of gas molecules constant.

$$\frac{p_1 . V_1}{T_1} = \frac{p_2 . V_2}{T_2}$$

Supposing a 4 liter helium balloon is released by a child when it is 20 °C outside. Knowing that the balloon bursts when its volume reaches 7 liters at a temperature of 275K, what is the pressure on the balloon when it gives out?

____

____

____

N.B. Your teacher will give you other exercises on this subject.

Back to the Stirling engine

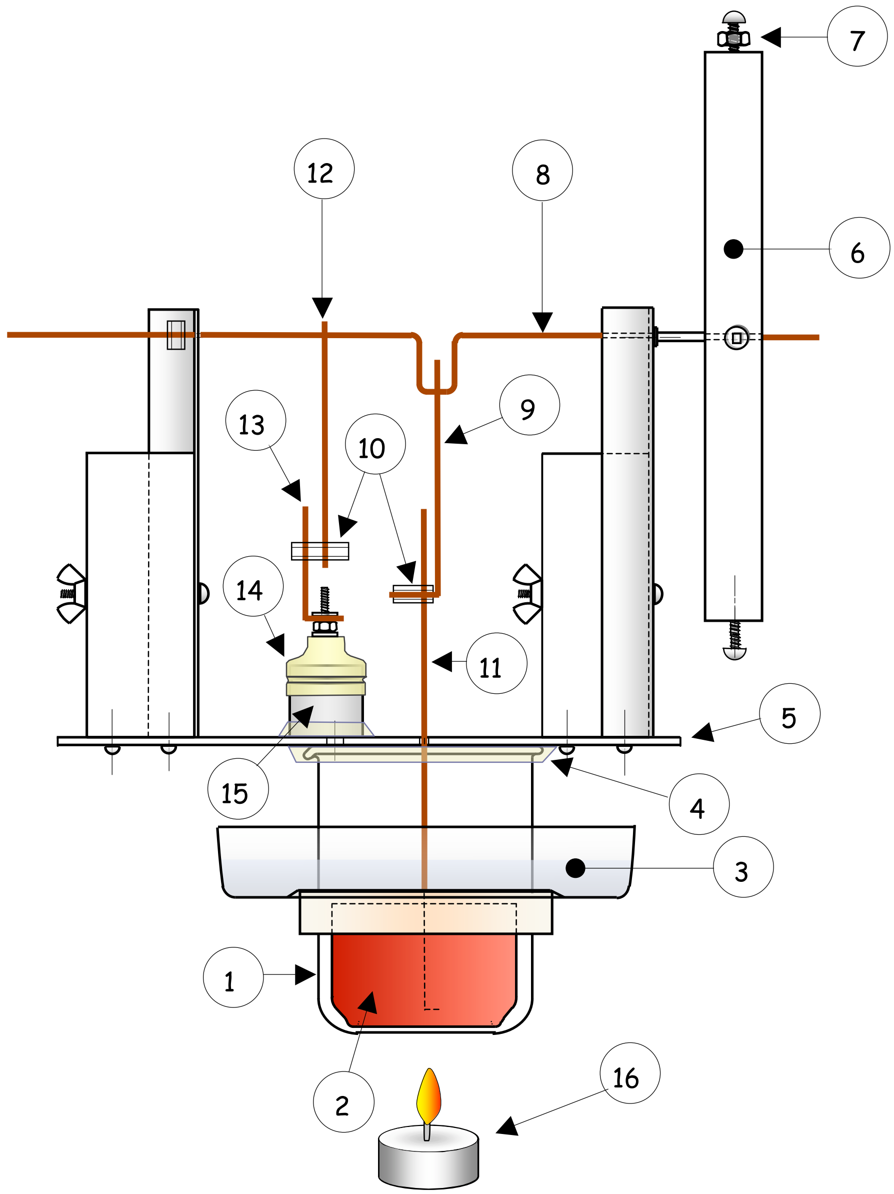
Outlining the mandate following learning activities

What do you have to do to fulfill this mandate?
(Analyse a Stirling engine)

Nomenclature of the Stirling engine

Your study of the behaviour of gases should help perfect your analysis of its function. But before analysing a Stirling engine's function, it is preferable to see one with your own eyes, turning in front of you. The engine we will present to you is practically functional. All it needs are a few adjustments. To start, let's see its different components.

N°.	Designation
1	400 mL beaker
2	Gas displacer
3	Cooling container
4	Hot glue joint
5	Support plate
6	Flywheel
7	Adjustment screw and nut
8	Crankshaft
9	Displacement rod
10	Linkage tubes
11	Line out of displacer
12	Membrane rod
13	Line out of the membrane
14	Membrane
15	Expansion chamber
16	Heat source



Stirling engine operating guide

Now please follow this advice to operate the Stirling engine.

1. Affix the engine using a universal clamp and support by inserting the clamp under the cooling container (3).
2. Place an unlit candle under the beaker and adjust the support so that the eventual flame will be very close to the beaker without actually touching it.
3. Disconnect the membrane rod (12) and the line out of the membrane (13) by sliding them out of the linkage tube (10).
4. Turn the crankshaft (8) by activating the flywheel (6). Adjust the displacer linkage tube (10) so that the displacer (2) moves freely without hitting the top or bottom of the beaker.
5. Lubricate all zones where friction risks slowing the motion. You must be certain that each part moves without jamming or hesitation.
6. On the flywheel (6), completely compensate for the mass of the displacer using the adjustment screw and nut (7) as counter weights. You should be able to place the flywheel (6) at any position without it moving afterwards.
7. Fill the cooling chamber (3) with ice and water. Be careful of overflow: the chilled water must not enter into contact with the base of the beaker when it is burning hot. The Pyrex of the beaker would not withstand it.
8. Light the candle under the beaker and wait at least three minutes for adequate heating. You may need two candles if the flame is small.
9. Make sure the hole in the support plate (5) through which the line out of the displacer (11) passes is airtight by adding a drop of oil.
10. Check the air tightness of the system by turning the flywheel. When the displacer is toward the top, the membrane (14) should expand. Conversely, when the displacer is toward the bottom, the membrane should contract. If the membrane does not move this way, the system is not airtight or the engine has not attained operating temperature. The problem must be corrected before going any further.
11. Now connect the membrane rod (12) and line out of the membrane (13) by sliding them through the linkage tube (10). Adjust the membrane linkage tube so that the elasticity of the membrane creates no resistance to the engine's rotation. The membrane may have to slide on the expansion chamber (15) to adjust the amplitude of the motion.
12. Now start the engine. Begin the rotation so that the displacer moves before the membrane does. For example, if the displacer rod (9) is at the top of its rotation, the membrane rod (12) should be moving upwards.

Analysis of the laboratory Stirling engine

This is it, your engine is turning and you know enough about this field to explain what's going on. An excellent way to describe a phenomenon in movement like this one is to use a comic strip. We are therefore asking you to describe, qualitatively, what is going on during a full rotation of the engine. It goes without saying that the **general law of gases** should colour each of your explanations. Your comic strip must be composed of four commented images.

Before beginning your comic strip, however, complete the following table. It deals with the role of each component of the engine and should orient your thinking.

The role of each component

N°.	Component	Role of the component
1	400 mL beaker	
2	Gas displacer	
3	Cooling container	
4	Hot glue joint	
5	Support plate	
6	Flywheel	
7	Adjustment screw and nut	
8	Crankshaft	
9	Displacement rod	
10	Linkage tubes	
11	Line out of displacer	
12	Membrane rod	
13	Line out of the membrane	
14	Membrane	
15	Expansion chamber	
16	Heat source	

Your comic strip

Drawing number 1
Complete explanation of the phenomenon
Justifications using concepts and laws

Drawing number 2
Complete explanation of the phenomenon
Justifications using concepts and laws

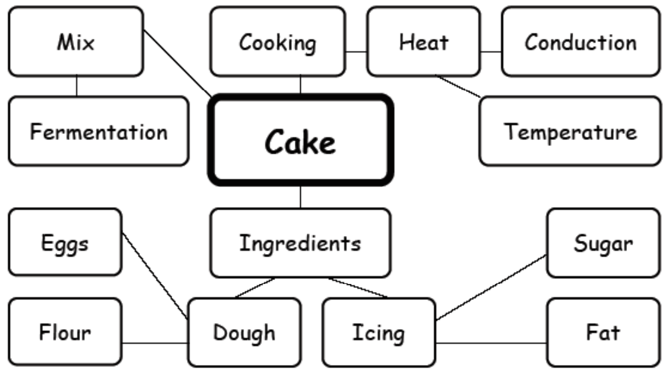
Drawing number 3
Complete explanation of the phenomenon
Justifications using concepts and laws

Drawing number 4
Complete explanation of the phenomenon
Justifications using concepts and laws

Integration and reinvestment

In the light of the study of the engine, rebuild a network of concepts related to the study of the operation of the Stirling engine. The new network you will build will no doubt be quite different from the one you built at the very beginning of this activity. This exercise will allow you to appreciate the road travelled while studying this fabulous engine.

Example of a network of concepts



Network of concepts

Stirling engine

Reflection

We now invite you to use the competencies acquired to go a little further in your thinking. To do so, you must produce a document that can take the shape of a Power Point presentation, a poster or simply a written document.

The document must briefly touch upon the following subjects:

1. Identify the advantages and disadvantages of the Stirling engine in relation to current internal combustion engines.
2. Think about the future of the Stirling engine in the light of environmental considerations.

The Stirling engine may also be used as a refrigeration device. The scientific principles in question in that case are identical to those in refrigeration machines in current use (air conditioner, freezer, refrigerator…) Since you now understand these principles, also touch upon the following subject:

3. Briefly explain the function of the refrigeration machine of your choice on the basis of the principles learned during the study of the Stirling engine.

Work plan

Webography

1. Diesel and gas engines (principles, output, …) http://www.ifp.fr/espace-decouverte-mieux-comprendre-les-enjeux-energetiques/les-cles-pour-comprendre/automobile-et-carburants/les-moteurs-conventionnels
2. Stirling Engine (principles, output, …) http://en.wikipedia.org/wiki/Stirling_engine
3. Advantages and disadvantages of the Stirling engine http://www.moteurstirling.com/avanconvenient.php
4. Applications for the Stirling engine (French)

   http://www.eco-energie.ch/content/view/112/47/

   http://www.moteurstirling.com/applications2.php

   http://www.moteurstirling.com/applications1.php